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R. E. Thomas, et al

Robert S. Kerr Water Research Center
Ada, Oklahoma

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by

R. E. Thomas and James P. Law, Jr.

Prepared for Presentation at the
Symposium on the Use of Sewage Effluent for Irrigation

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Robert S. Kerr Water Research Center
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SOIL RESPONSE TO SEWAGE EFFLUENT IRRIGATION

by

R. E. Thomas and James P. Law, Jr.*

Our present methods of discharging sewage and industrial wastes to surface waters have exceeded the assimilative capacity of many receiving streams. The resulting pollution poses a serious threat to our water supply. This threat is stimulating an intensive quest for treatment processes which will greatly reduce the pollutional load that wastewaters contribute to our surface waters. Reuse of wastewater for crop irrigation qualifies as one such process. The application of wastewater to agricultural land serves the following purposes: promotes growth of crops; conserves water and nutrients that are normally wasted; provides economical treatment of the wastewater; and reduces the pollutional load on our surface water supplies.

Much of the literature on the use of soil for treatment of wastewater has been covered in three recent publications. Two of these (1,2) are review articles while the third (3) is an annotated bibliography. One of the reviews deals with the use of soil systems for treatment of pulp and papermill wastewaters. The other review is a comprehensive report on the use of the soil for treatment of wastewater. The annotated bibliography covers agricultural use of

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sewage effluent and sludge. The more than 600 literature citations listed in these publications constitute an excellent cross section of the available literature.

The objective of this paper is to summarize our present knowledge of the treatment of wastewater by applying it to the surface of the soil. Brief sections on the present use and design of soil systems and wastewater quality are followed by a discussion of the interactions which result from the application of wastewater to a plant ecosystem. This paper is limited to the response of the soil and the effect on the soil water.

Use of Soil Systems

A recent survey (4) reported that about 1,300 soil systems employed surface application in the United States in 1964. About two-thirds of these systems were being used specifically for wastewater treatment. Crop benefits were not an important consideration in such operations. In the remaining one-third of the systems, irrigation of crops was the primary objective. There were as many systems in cool, humid regions as there were in warm, arid regions; and the systems were installed in soils ranging in texture from clay to sand. This survey showed that soil systems can be used successfully throughout the United States for wastewater treatment. To date, the emphasis has been on wastewater treatment rather than crop irrigation.

System Designs

The soil systems designed for surface application of wastewater can be grouped as follows: (a) infiltration basins, (b) ridge-and-furrow, (c) spray-irrigation, and (d) spray-runoff. Infiltration basins are generally small, diked areas in permeable formations. They have been used successfully as the final polishing step in the comprehensive treatment of wastewater for direct reuse (5,6). Ridge-and-furrow systems are similar to infiltration basins except that furrows are constructed across the bottom of the diked area and vegetation is established on the ridges between the furrows, These systems have been used extensively in parts of the United States for treating a variety of wastewaters (7). Spray-irrigation systems can cover large areas and take advantage of the natural terrain. Some objectives of existing spray-irrigation systems include improved crop yields (8), stabilization of wind-blown sands (9), water conservation (10), and treatment of industrial wastes (11). Spray-runoff is a special adaptation of the spray-irrigation system. It operates better when natural sloping terrain is terraced to separate small land areas and to collect the runoff from these areas. This system has been used successfully to treat cannery wastewater and return a substantial portion of the purified wastewater to a receiving stream (12,13).

Wastewater Quality

The response of the soil to irrigation with wastewater is dependent on the quality of the applied wastewater. The quality of the wastewater is determined by its source. For example, the wastewater from semichemical pulping (14) is much different than that from food processing (15) or from farm animal wastewaters (16). The degree of treatment also influences the quality of a wastewater. Primary sedimentation of municipal sewage may remove 25 to 40 percent of the suspended solids load, while good secondary treatment processes may remove up to 95 percent of the suspended solids. Such variations in wastewater quality make it difficult to generalize on the response of the soil to irrigation with wastewater.

The suitability of domestic wastewaters for irrigation depends mainly on the chemical composition of the municipal water supply and how this composition is affected by the municipal use cycle. One use cycle may contribute 100 to 450 ppm of total dissolved solids (17). Increases greater than this can usually be attributed to industrial sources. Any wastewater derived from a single municipal water use cycle will usually be acceptable for most irrigation applications.

Industrial wastewaters may contain toxic quantities of a variety of minerals. Wilcox (18,19) has pointed out the toxic effects of many different types of industrial pollutants and has made recommendations for their control in areas where these industrial wastewaters are to be used for irrigation. Industrial wastewaters which are high in organic constituents, such as those from food processing and paper and pulp processing, are well suited to use for irrigation.

The general subject of water quality for irrigation has been well documented and discussed by numerous investigators (20-24). Salinity and the ratio of sodium to calcium and magnesium are important factors in judging the suitability of water for irrigation. Municipal water softening greatly increases the relative abundance of sodium. This is directly opposed to the desired ratio for irrigation water. This undesirable change was recognized long ago by Scofield and Headley (25) who made the frequently quoted statement: "Hard water makes soft land, and soft water makes hard land."

Wastewater Effects on the Soil

A soil system is composed of gas, water, microorganisms, and minerals which form the solid matrix. Experience has taught us that this dynamic system is constantly undergoing physical, chemical, and biochemical interactions. Wastewater applied to the soil mixes with the existing soil water becoming a part of the system, and may alter the nature and rate of change of the physical, chemical, and biochemical processes in the soil system. Some of the effects of wastewater on the physical and chemical properties of the soil and on the quality of the groundwater will be discussed in the following paragraphs.

Many insoluble constituents such as suspended minerals, particulate organics, and inorganic precipitates are quickly filtered out of the moving liquid in the surface horizon of the soil. These substances are subject to alteration and degradation, but some of this material becomes a permanent part of the soil. Soluble constituents may penetrate deeper into the profile before interacting with the soil

system, or they may pass through the soil profile relatively unaltered. Irrigation with wastewaters may produce beneficial or detrimental changes in the soil system. A successfully designed system balances these changes to prevent the detrimental effects from defeating the purpose of the system.

Physical clogging of the soil pores and the resulting loss in the infiltration rate have caused many wastewater-soil treatment systems to fail. Many factors related to the cause of the clogging have been identified (26-31). Some of these are as follows: anaerobic conditions in the soil promote rapid clogging; clogging is related to the changes in the physical, chemical, and biochemical processes in the soil; and the most severe clogging occurs very near the soil surface. Empirical evaluations (5,29,31,32) have shown that the rapid clogging associated with anaerobic conditions in the soil is closely related to the frequency of application. Such clogging has not been associated with frequencies which permit substantial soil drying between each application; therefore, this type of clogging would not be a serious problem at the application frequencies used for irrigation.

The potential hazard of high sodium ratios to the physical properties of certain soils has already been mentioned. This phenomenon has been studied extensively for the improvement of saline and alkali soils by the proper management of irrigation practices (24). The same principles would apply where wastewaters are being used for irrigation. Wastewaters also contribute suspended mineral and organic solids to

the soil. Such mineral additions have increased the clay content of sands (9). It is well known that additions of organic matter improve the aggregate stability of soils, and wastewaters high in organics have been used to improve the physical properties of soils (33).

Information presently available makes it possible to use wastewater for irrigation without seriously damaging the physical properties of the soil. In some cases, irrigation with wastewater can be used to improve the physical properties of soils.

Irrigation with wastewater has a marked influence on the chemical equalibria in the soil. Organic matter and clay added in the suspended solids can increase the cation exchange capacity of the soil (9). The chemical composition of wastewater usually differs from that of freshwater normally used for irrigation. Many wastewaters are high in monovalent cations such as sodium and ammonium. These monovalent ions displace divalent ions such as calcium and magnesium on the cation exchange positions (34). Such exchanges can be detrimental to the properties of soils high in clay; however, this has not been a serious problem in wastewater irrigation.

Many of the dissolved chemicals in wastewaters influence the suitability of the soil for crop production. Nitrogen and phosphorus compounds have a beneficial fertilizer value when retained in the soil and utilized by the crops. If they are not assimilated by crops, they may become a pollution problem. Pollution of groundwater by nitrates which move freely in the soil can be a serious

problem (35,36). Release of phosphorus from soils to our surface waters can also contribute to pollution (37). Elements which are toxic to plants are present in some wastewater in sufficient quantities to limit its use. Boron content has caused concern in areas where boron-sensitive crops are irrigated with wastewater (32). Toxic concentrations of copper and zinc have apparently accumulated in the soil at two sewage farms (38), but it has taken over a century for these toxic conditions to develop.

Much remains to be learned about the chemical changes in the soil resulting from irrigation with wastewater. The effects noted here are only a few of those which can and probably do occur. For example, phosphorus fixation is a well-established process and could account for storage of large amounts of phosphorus applied to certain types of soil. Nitrogen undergoes many transformations in the soil environment. Certain soils exhibit ammonia fixing capacities; relatively immobile forms of nitrogen are nitrified to the mobile nitrate form; and conversely, the mobile nitrate form can be reduced to an immobile form or denitrified to a gaseous form. Our present understanding of the effects of wastewater irrigation on the chemical behavior of the soil suggests that this is an advantageous method for conserving water and plant nutrients.

Wastewater Effects on Soil Water

Soil is not only a medium for plant growth but also a potential medium for treatment of a variety of wastes. Many processes interact to change the character of sewage effluents applied to the soil. Among these are dilution with existing soil water, biochemical oxidation of the organic constituents, and cation exchange with clays and organic colloids (humus).

Several studies are reported in which the effects of irrigation with wastewaters on the quality of the percolating soil water have been investigated. Reed Canary grass was irrigated with sewage effluent in both lysimeter and field studies to determine how much effluent could be applied, the benefits to the crop, and the effect on the chemical content and microbial population of the percolating waters (39). It was found that 40 inches or more of sewage effluent could be applied to Reed Canary grass during the growing season under normal weather conditions. The crop and soil effectively removed almost all of the nitrogen, phosphorus, and potassium from the percolating waters. High sodium content in the effluent displaced calcium and magnesium from the soil exchange complex. The loss of calcium and magnesium can be detrimental to soil fertility, and the accumulation of sodium may be harmful to soil structure and other physical conditions. Crop yields were substantially increased by plant nutrients in the effluent as compared to irrigation with fresh water. Percolation through the soil reduced the coliform index from 10 million to less than 100 and in most wells tested to less than 10.

An extensive study of sewage spreading on five California soils was conducted by the Sanitary Engineering Research Laboratory at Berkeley (34). No crops were grown in the lysimeters, and the effects observed were limited to the interactions of the soils and sewage effluents. Cation exchange between the soils and percolating water resulted in increased concentrations of calcium and magnesium in the percolate and decreases in sodium and potassium. Aerobic conditions prevailed for the first few weeks of sewage application, but anaerobic conditions soon developed and persisted thereafter. This adversely affected ammonia, phosphate, and BOD removals. No dissolved oxygen was found in the percolate from sewage applications, and sulfates were reduced to sulfites under anaerobic conditions. Results such as these stress the importance of intermittent dosing with drying periods and aeration between, such as would be achieved under good agricultural irrigation management.

A recent study of a ridge-and-furrow treatment system in Wisconsin has been reported (40). The system takes the flow from a high-rate trickling filter at an average rate of 140,000 gpd. Reed Canary grass is grown on the four basins which operate in pairs alternating on a weekly basis. Soil percolate samples were collected at 1-foot and 3-foot depths. Removals at the 3-foot depth were found to be 88 percent of the BOD, 70 percent of the total nitrogen content, and 93 percent of the phosphate. The results showed that a vegetated soil treatment system provides a high degree of nutrient removal and can be operated satisfactorily in northern latitudes.

Wastewater renovation by irrigation of forest lands has recently been reported (41). Nitrogen, phosphorus, and organics were removed from the wastewater to the extent that the method is offered as a solution to both water pollution and water supply problems which are prevalent in many areas.

Results of the above studies are remarkably similar despite substantially varied operating conditions. System types include spray-irrigation and ridge-and-furrow. The studies were conducted in both warm, semiarid and in cool, humid climates. These results indicate that variations in climate and system design have no major effect on the quality of the percolating soil water.

Summary

Recent emphasis on water pollution control has stimulated research on the application of wastewaters to the land. About two-thirds of the more than 1,300 systems in operation were designed for treatment of a wastewater rather than irrigation of economic crops. A variety of needs and empirical solutions have resulted in the evolution of several system designs. Each of these designs have advantages for particular operating conditions and needs. Some wastewaters are unsuitable for irrigation use because of the addition of toxic or excessive concentrations of pollutants during the use cycle. Many industrial and most domestic wastewaters are suitable for irrigation use under good management practices. Wastewater can cause beneficial or detrimental changes in physical and chemical properties of soil. Good management practices and system design features can make the beneficial effects greater than the detrimental effects. Wastewaters receive treatment as they percolate through soil. Systems can be designed and operated to accentuate this treatment. The resulting soil percolate is immediately suitable for many reuse purposes.

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R. E. Thomas and James P. Law, Jr.

Discussion Prepared by Dr. John J. Kolega, Recorder

Question: In general, which would be better for a source of irrigation water--a sewage effluent or the conventional water supply that has been used?

Discussion:

If there were a choice, a sewage effluent would be preferred. There is a benefit to be derived from the organic matter as well as the nutrients contained in the sewage effluent.

A related factor is the use that is made of the water in its cycle through the municipality. For example, if salinity is high, a more salt tolerant crop may be needed. It has been reported that the dissolved solids increase for one municipal use cycle will range from 100 to 600 ppm.

Question: What is the value of dissolved phosphorus and nitrogen in a sewage effluent as a supplemental fertilizer?

Discussion:

This was not calculated, but there would be a net gain. The sewage effluent alone probably would not be high enough in the above mineral content to eliminate the need for additional fertilizer.

Question: How much sewage effluent can be applied before anaerobic conditions in the soil can be expected?

Discussion:

A number of factors are involved, such as soil characteristics and climatic variables. However, it would probably be difficult to cause anaerobic conditions to exist under normal irrigation practices. If the sewage effluent were low in organic content (suspended solids), the hydraulic loading rate could be greater.

One of the primary requirements for irrigation is that the soil be well drained. The soil needs to drain after each loading cycle if good aeration is to be maintained. Good management and proper scheduling will be required. Temperature and the organic load also are factors to be considered.

Question: What are the problems associated with the application of too little or too much sewage effluent?

Discussion:

At low rates of application, e.g., insufficient leaching of accumulated salts, there might occur a buildup of toxic quantities of salts in the plant root zone.

Excessively high rates of application tend to cause clogging of the soil surface, greatly reducing infiltration rates.

Question: How would you compare the principles involved with conventional irrigation practice to that for irrigating with sewage effluent?

Discussion:

There is not going to be much difference. If salts are involved, there will be a problem if their movement does not go below the crop root zone. Under top management conditions, there will not be a problem.

Question: What is your definition of soil systems as referred to in your paper?

Discussion:

This is a system designed to use soil to treat a liquid waste on a continuous basis.

Question: For the number of soil systems referred to in your paper on page 2 (1300) and on page 12 (2000), was there any variation geographically speaking? What is the difference between the numerical values given?

Discussion:

The number 2000 is in error and should be 1300. This is the number of surface application soil systems reported by the survey in 1964. This includes land disposal systems as well as those in which the irrigation of crops is the primary concern. These 1300 soil systems were scattered throughout the United States with more in some states than in others, but there was no significant variation on a geographic basis. The systems were designed primarily for small communities where further sewage treatment was desired before effluent discharge. In many of these systems there was no interest in crops with the soil function being one of stabilization and further treatment of the sewage effluent. A difference in design purpose was noted between northern and southern climates.

The largest amount of wastewater applied to soil was reported in California followed by Texas. A helpful reference on the subject is an article by P. W. Eastman (ASCE, Jour. Irr. & Dr. Div., Vol. 93, IR3, pp. 25-31. 1967).

Question: What problems are involved for year-round utilization of sewage effluent in an irrigation system?

Discussion:

The major problem is the requirement that the effluent be utilized come rain or shine. In Lubbock, Texas, reservoirs are used to store the effluent during periods of rain or when it is necessary to dry the fields for cultivation, harvest, etc. Grasslands that can be irrigated in all seasons give such a system good buffer capacity.

Question: Where is irrigation with sewage effluent primarily being used?

Discussion:

It is being used mainly by the smaller cities. It is not known whether this practice will eventually be used by larger cities having populations of one million or more. Perhaps this is unlikely because of the large areas required.

Question: How many of the 1300 soil systems cited in the paper are located in wooded areas?

Discussion:

The answer to this question could not be given.

Question: Describe the comparative benefits of sewage application to soils in the categories of sand, clay, and loam.

Discussion:

An overall benefit is the addition of organic matter. Specifically with the sandy soil, it will become more crumbly and tend to build loam characteristics with the addition of organic matter. With clay soil there would be an improvement in soil aggregate stability and structure. A loam would exhibit improved soil structure and an increase in cation exchange capacity. Generally speaking, soils become more fertile and are more easily tilled.

Question: Is the amount of sodium that is used in household detergents a factor with this type application?

Discussion:

Many true soaps are sodium salts of fatty acids, but the modern synthetic detergents usually do not contain sodium salts. However, in cities where there is a hard water condition and individual household softeners are used, this will upset the sodium-calcium ratio and result in a preponderance of sodium in the wastewater. It is generally believed that water softeners contribute much greater amounts of sodium than do household detergents. One needs to know more about the quantity of sodium involved, the ratio of sodium to divalent cations, and the soil type involved before this can be answered in more detail. Sodium buildup can be detrimental to clay soils. Another comment was that the sodium contribution would be so diluted that it probably would not be of great concern.

Question: Where does denitrification occur and what is the relationship of the concentration of dissolved oxygen?

Discussion:

This is a debatable topic and studies are being conducted in this area. Based upon laboratory studies, it is the opinion of the speaker that the dissolved oxygen concentrations must be zero for denitrification to occur.

Question: What can be said about the relationship of organic matter to the amount of water added?

Discussion:

Application rates should be discussed in terms of organic matter per unit volume applied. This ratio should be low enough or the soil permeable enough so that infiltration is not seriously impaired. Higher hydraulic loadings would be permitted when the effluent has been subjected to a good secondary treatment process.